# Triple Bottom Line Cost Benefit Analysis of Green Infrastructure/Low Impact Development (GI/LID) in Phoenix, AZ

**Results Report**

**Prepared by Autocase for the City of Phoenix**

June 20th, 2018

City of Phoenix

Stantec

Autocase

The Nature Conservancy
Protecting nature. Preserving life.

Watershed Management Group

# Glossary of Terms

| | |
|---|---|
| BCR | Benefit Cost Ratio |
| CBA | Cost Benefit Analysis |
| CAC | Criteria Air Contaminants |
| CapEx | Capital Expenditure |
| CBA | Cost Benefit Analysis |
| $CO_2e$ | Carbon dioxide equivalent |
| EPA | U.S. Environmental Protection Agency |
| eGrid | Emissions grid |
| GHG | Greenhouse Gas |
| GWP | Global Warming Potential |
| M | Million |
| MWh | Megawatt-hour(s) |
| NPV | Net Present Value |
| $NO_x$ | Nitrogen Oxide |
| $N_2O$ | Nitrous Oxide |
| PM | Particulate Matter |
| $PM_{2.5}$ | Particulate Matter Smaller than 2.5 micrometres |
| $SO_2$ | Sulfur Dioxide |
| TBL | Triple Bottom Line |
| TBL-CBA | Triple Bottom Line-Cost Benefit Analysis |
| TBL-NPV | Triple Bottom Line-Net Present Value |
| USD | U.S. Dollars |
| VOCs | Volatile Organic Compounds |

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# 1 Introduction

## 1.1 Project Background

Stantec, Autocase, and Watershed Management Group (WMG) were engaged by the City of Phoenix (City) – with The Nature Conservancy (TNC) as a contributing and reviewing partner – to perform a triple bottom line cost benefit analysis (TBL-CBA) of various Green Infrastructure/Low Impact Development (GI/LID) features, as well as look at the triple bottom line impacts of three case study sites in the area.

The TBL-CBA business case was conducted in Autocase - a cloud-based software tool, to provide insights into the net present value (NPV) of costs and benefits of the projects to the City, as well as the broader societal and environmental impacts over a 50-year time horizon using a 3% discount rate to convert all future cash flows into a present value.

TBL-CBA is a systematic evidence-based economic business case framework that uses best practice Life Cycle Cost Analysis and Cost Benefit Analysis (CBA) techniques to quantify and attribute monetary values to the Triple Bottom Line (TBL) impacts resulting from an investment. TBL-CBA expands the traditional financial reporting framework (such as capital, and operations and maintenance costs) to also consider social and environmental performance. TBL-CBA provides an objective, transparent and defensible economic business case approach to assess the costs and benefits pertaining to the project being analyzed.

This study provides information for City projects and private development that may want to implement and incorporate GI/LID facilities. The costs and co-benefits of GI/LID features in the Phoenix environment need to be evaluated to identify the benefits and aid in potentially identifying to which stakeholders they accrue. The City identified key motivating factors for this study, as follows:

1. The need to evaluate the following key parameters:
    a. Financial costs and benefits;
    b. Carbon emissions and air pollution;
    c. Heat island impacts;
    d. Water quality improvement;
    e. Flood risk reduction;
    f. Property value uplift.
2. The need to identify and ensure a common understanding of benefits vs. initial costs vs. life cycle costs
3. The need to provide recommendations on appropriate feature types according to associated costs and benefits.

Given the importance of heat stress in Phoenix, instead of using historical temperatures this report incorporates future climate change in to its analysis. Taking the emissions pathway RCP8.5 "higher emissions" scenario from NOAA's climate explorer (NOAA, 2018), the analysis incorporates future temperature and rainfall predictions for Maricopa County in to Autocase. In so doing, the results will aid in resilience decision-making related to urban heat island.

Local data were used whenever possible and available; information from various sources, such as EPA's SUSTAIN database and the National Stormwater Management Calculator was used to supplement any gaps and are identified throughout the report.

## 1.2 Report Structure

This report consists of two analyses: one for the general 1,000 sq ft feature types, and one for the three case study sites.

In Chapters 2 and 3 are the project description and results for the general feature analysis, which investigates generalized costs (on a per-1,000 sq ft basis) and benefits of six feature types that may be utilized in the City of Phoenix. The features that will be analyzed are:

1. Concrete
2. Swale
3. Bioretention basin
4. Infiltration trench
5. Pervious pavers
6. Porous concrete
7. Porous asphalt

In Chapters 4 and 5 are the project description and results for three GI/LID case studies, which looks at costs and benefits of three specific projects previously implemented in the Phoenix Metro area (Primera Iglesia, Glendale Community Center, and a combined project of Central Station/Civic Space Park/Taylor Mall).

A combined Conclusion and Policy Analysis section intended to help the City of Phoenix make broad decisions on overall GI/LID feature implementation in Phoenix, while recognizing that projects should be evaluated on an individual basis to determine TBL results and which features might be most beneficial for specific sites. Information on specific methodology used for the analyses is included in Section 8.

## 1.3 Project Parameters

The specific parameters – or impacts – to be assessed for each feature type (including concrete) in Autocase are:

| Impact Type | Cost/Benefit |
|---|---|
| Financial | Capital Expenditures (CapEx) |
| Financial | Operations and Maintenance (O&M) |
| Financial | Avoided CapEx on Additional Detention |
| Financial | Avoided O&M on Additional Detention |
| Financial | Avoided CapEx on Additional Piping |
| Financial | Avoided O&M on Additional Piping |
| Financial | Replacement Costs |
| Financial | Residual Value of Assets |
| Social | Heat Island Effect (Mortality) |
| Social | Heat Island Effect (Morbidity) |
| Social | Flood Risk |
| Social | Property Value |
| Environmental | Water quality |
| Environmental | Carbon Emissions from Concrete |
| Environmental | Air Pollution Reduced by Vegetation |
| Environmental | Carbon Reduction by Vegetation |
| Environmental | Air Pollution from Energy Use Reduction |
| Environmental | Carbon Emissions from Energy Use Reduction |

A description of each parameter and the associated valuation methodology is included in Section 8.3.

## 1.4 Summary of Feature Costs

Table 1 outlines the capital expenditure (CapEx) and annual operations and maintenance (O&M) costs that are used to evaluate the features throughout the report. Details on their sources and how they were derived is given within each feature's description below. Local and site-specific values were used where possible. If those were not available, either Autocase estimates were used (informed by EPA's SUSTAIN database), or the National Stormwater Management Calculator values were used.

*Table 1: Summary of Feature Costs*

| Feature | | Unit | Cost ($) | | |
|---|---|---|---|---|---|
| | | | Low | Expected | High |
| Concrete | CapEx | $ per 1,000 sq ft | $4,500 | $5,750 | $7,000 |
| | O&M | $ per 1,000 sq ft | $0 | $0 | $0 |
| Swale | CapEx | $ per 1,000 sq ft | $1,124 | $5,527 | $11,358 |
| | O&M | $ per 1,000 sq ft | $97 | $120.95 | $151 |
| Porous concrete | CapEx | $ per 1,000 sq ft | $6,370 | $7,000 | $10,670 |
| | O&M | $ per 1,000 sq ft | $12 | $24 | $48 |
| Bioretention basin | CapEx | $ per 1,000 sq ft | $2,000 | $3,000 | $4,000 |
| | O&M | $ per 1,000 sq ft | $97 | $121 | $151 |
| Infiltration trench | CapEx | $ per 1,000 sq ft | $400 | $1,450 | $4,200 |
| | O&M | $ per 1,000 sq ft | $97 | $121 | $151 |
| Pervious pavers | CapEx | $ per 1,000 sq ft | $7,540 | $12,970 | $17,800 |
| | O&M | $ per 1,000 sq ft | $12 | $24 | $48 |
| Underground stormwater storage | CapEx | $ per 1,000 cubic ft | $904 | $1,205 | $1,506 |
| | O&M | $ per 1,000 cubic ft | $1 | $1 | $6 |
| Trees | CapEx | $ per tree | $160 | $591 | $739 |
| | O&M | $ per tree | $12 | $16 | $20 |
| Planter boxes | CapEx | $ per 1,000 sq ft | $550 | $8,000 | $24,500 |
| | O&M | $ per 1,000 sq ft | $97 | $121 | $151 |
| Retention basin | CapEx | $ per 1,000 cubic ft | $4,260 | $11,550 | $22,710 |
| | O&M | $ per 1,000 cubic ft | $15 | $30 | $60 |
| Porous asphalt | CapEx | $ per 1,000 sq ft | $2,840 | $6,330 | $9,470 |
| | O&M | $ per 1,000 sq ft | $12 | $24 | $48 |
| Shrubs | CapEx | $ per 1,000 sq ft | $109 | $218 | $355 |
| | O&M | $ per 1,000 sq ft | - | - | - |

**Notes:**

- **O&M for shrubs is included within the O&M cost of specific features (e.g., bioretention basin, bioswale, etc.).**

## 1.5 Common Inputs

The following section illustrates the inputs used for the project, including information about the city, the financial assumptions, and specifications about each feature type analyzed with Autocase. These variables were kept standard across all feature type evaluations.

*Table 2: Common Inputs*

| Input | Unit | Value | Notes |
|---|---|---|---|
| **Dominant soil type** | | B | |
| **24-hour design storm** | Inches | 1 | A 0.5-inch and 2-inch storm were also assessed, with results for these analyses in Section 10.1 and 10.2. |
| **Stormwater model** | | TR-55 | |
| **Operations duration** | Years | 50 | |
| **Construction duration** | Years | 1 | |
| **Discount rate** | % | 3% | |

# 2 Project Description (GI/LID Feature Types)

This section outlines the GI/LID feature types that are analyzed in this report, as well as states the more detailed design assumptions used in order to generate results within Autocase.

## 2.1 Features to be Analyzed

The list of GI/LID features to be analyzed in this general feature analysis section are:

1. **Rain garden/Bioretention basin:** shallow earthen depressions that collect stormwater runoff into native soils to support planted vegetation.
2. **Swale:** rock or vegetated swales are open, shallow channels that are designed to slowly convey runoff flow to downstream discharge points.
3. **Infiltration trench:** a channel-like subsurface excavation that has been filled with gravel to provide large pore spaces for stormwater to infiltrate.
4. **Pervious pavers:** Also called interlocking porous concrete pavers, these permeable surfaces use the spaces between the pavers to infiltrate water and can be designed to reduce peak runoff.
5. **Porous concrete:** a specific type of concrete with a high porosity used for flat work applications that allows rainfall to pass directly through and infiltrate the soil below.
6. **Porous asphalt:** allows rainfall to drain through the surface into a stone recharge bed and infiltrate the soil below.

Each of these features were analyzed individually against the key parameters through Autocase to evaluate 'standalone' costs and benefits. They each were then compared against a base case 'Concrete' feature type in Autocase to assess their *incremental* or *relative* impact. The concrete base case was chosen to reflect a more typical 'gray' site. To be able to compare and evaluate the various feature types, it was important this analysis use consistent control variables. Therefore, the size of each feature (including concrete) was kept consistent at 1,000 square feet, and a 15:1 watershed area was used to represent the surface area that would generate runoff flowing in to each feature. The same design storm event and other similar variables (detailed in Section 2.3.2–Common Inputs) were also kept consistent so any changes in costs/benefits would be attributable to the feature type.

## 2.2 Project Inputs

The following section illustrates the inputs used for the feature type analysis, such as depths, storage volume, and cost information.

### 2.2.1 Base Case Design Specifications (Concrete)

Concrete was used as the base case against which the GI/LID feature types were compared. This means the costs and benefits for the base case were assessed assuming that 1,000 sq ft of new concrete was constructed instead of a GI/LID feature.

*Table 3: 1,000 sq ft Feature Type Concrete Inputs*

| | Unit | Expected Value |
|---|---|---|
| **Name of feature** | | Concrete |
| **Area** | Sq ft | 1,000 |
| **Depth of coverage material** | Inches | 3 |
| **CapEx** | $ | $5,750<br>(Low = $4,500, High = $7,000) |
| **Annual O&M** | $ | $0 |

**Notes:**

- The low CapEx cost of $4,500 is for areas greater than 1,000 sq ft. The high CapEx cost of $7,000 is for areas less than 1,000 sq ft.
- Per City of Phoenix Street Maintenance Division, operation and maintenance costs for concrete sidewalk is $0 because no recurring maintenance is required. It is instead fully replaced when damaged/deteriorated. The average life for a concrete sidewalk in Phoenix (barring external forces) is 25-30 years. This is factored in to the life cycle cost model in Autocase and is reflected in the replacement cost.

### 2.2.2 GI/LID Feature Type Design Specifications

#### 2.2.2.1 Swale

*Table 4: 1,000 sq ft Feature Type Porous Swale Inputs*

| | Unit | Expected Value |
|---|---|---|
| **Name of feature** | | Swale |
| **Area** | Sq ft | 1,000 |
| **Maximum Ponding/Treatment Depth** | Inches | 9 |
| **Channel Bank Height** | Inches | 2 |
| **Soil type** | | B |
| **Maximum Surface Infiltration Rate** | Inches per hour | 4.5 |
| **Minimum Surface Infiltration Rate** | Inches per hour | 0.25 |
| **Infiltration Rate Reduction Factor** | per hour | 1 |
| **Capital Expenditure** | $ | $5,527<br>(Low = $1,124, High = $11,358) |
| **Annual O&M** | $ | $121<br>(Low = $97, High = $151) |

**Notes:**

- Based off the swale at Taylor Mall, 2nd to 3rd Street. Using Google Earth (address of 444 N. Central Avenue) to count trees and estimate shrubs and note the concrete curb and curb cut, fine grading within planting area; and using the plan sheets and cost lines. Used the plan sheets to measure lengths and widths.
- CapEx: Low does not include concrete removal or the concrete single curb, but does include 1 tree, 8 shrubs, 8 feet of curb cuts. Expected does not include concrete removal, but does include concrete single curb, 2 trees, 16 shrubs, 16 feet of curb cuts. High includes concrete removal, concrete single curb, 3 trees, 26 shrubs, 24 feet of curb cuts (8 openings, 3' each).
- O&M costs are from Watershed Management Group estimates based on $120/1,000 sq. ft. at a rate of $75/hr (low/high = +/- 25%).

*Figure 1: Swale*
*Source: City of Phoenix, Office of Environmental Programs.*

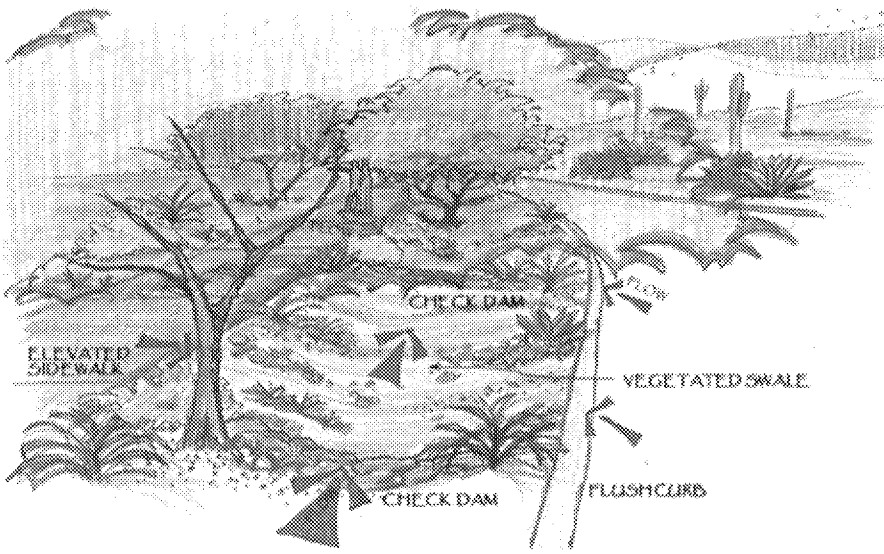


*Figure 2: Elements of a Swale*
*Source: PIMA County, 2015. “Low Impact Development and Green Infrastructure Guidance Manual”.*

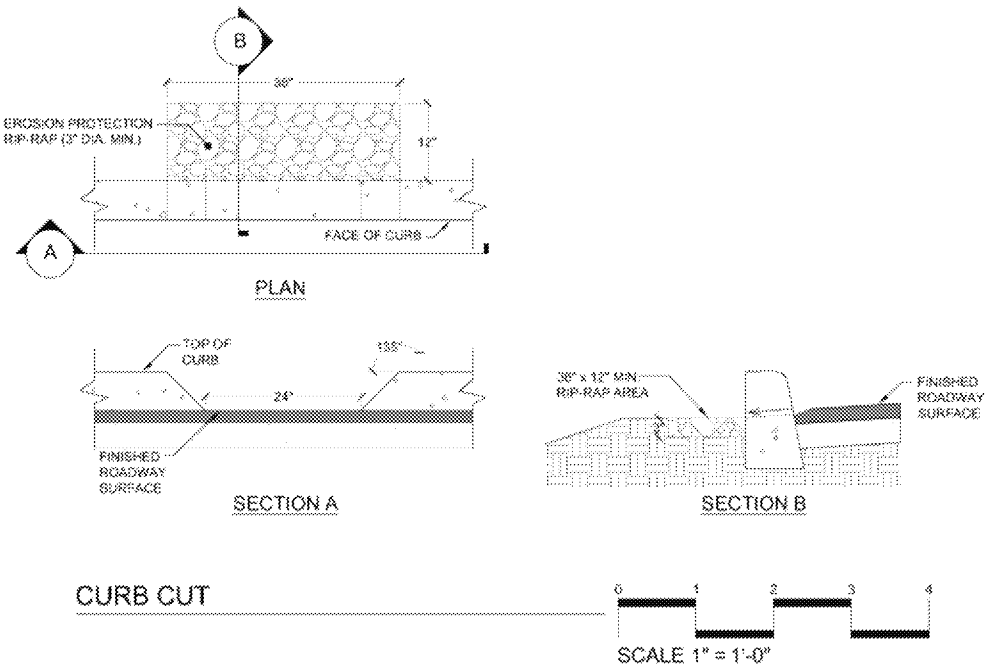


*Figure 3: Typical Curb Cut Design Detail*
*Source: WMG*
*Notes: Swales may use curb cuts to draw in water in to the feature, thus its inclusion here.*

#### 2.2.2.2 Bioretention Basin/Rain Garden

*Table 5: 1,000 sq ft Feature Type Bioretention Basin Inputs*

| | Unit | Expected Value |
|---|---|---|
| **Name of feature** | | Bioretention/Rain garden |
| **Area** | sq ft | 1,000 |
| **Maximum Ponding/Treatment Depth** | Inches | 6 |
| **Depth of Coverage Materials** | Inches | 3 |
| **Percent Empty Space in Material** | % | 40 |
| **Does this feature allow for infiltration?** | | Yes |
| **Trees Planted** | # | 3 |
| **Shrubs planted** | # | 28 |
| **Shrubs Average Expected Lifespan** | Year | 10 |
| **Shrubs Max Expected Lifespan** | Year | 20 |
| **Soil type** | | B |
| **Maximum Surface Infiltration Rate** | Inches per hour | 4.5 |
| **Minimum Surface Infiltration Rate** | Inches per hour | 0.25 |
| **Infiltration Rate Reduction Factor** | per hour | 1 |
| **CapEx** | $ | $3,000<br>(Low = $2,000, High = $4,000) |
| **Annual O&M** | $ | $121<br>(Low = $97, High = $151) |

**Notes:**

- Capital costs for Bioretention Basins are based on WMG's experience over the last decade in Tucson as well as the last 5 years in Phoenix designing and constructing basins. Costs include labor, design, curb cuts, shrubs, grasses, trees, rock and/or wood mulch, permitting, excavation and soil hauling. Costs vary depending on existing site conditions such as topography, land use, hardscape and soil type as well as if a curb cut is needed.
- O&M costs are from Watershed Management Group estimates based on $120/1,000 sq ft at a rate of $75/hr.

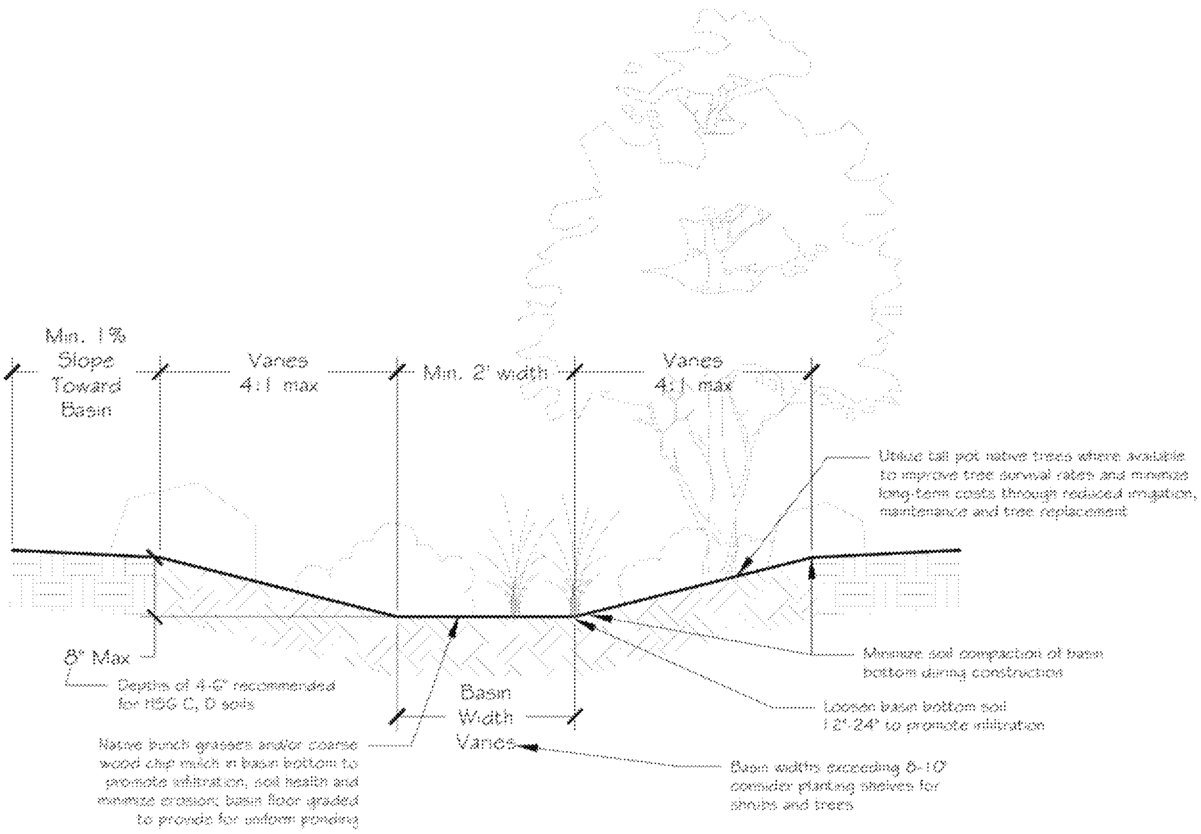


*Figure 4: Typical Bioretention Basin Cross-section*
*Source: Watershed Management Group*

*Figure 5: Bioretention Basin*
*Source: City of Phoenix, Office of Environmental Programs.*

#### 2.2.2.3 Infiltration Trench

*Table 6: 1,000 sq ft Feature Type Infiltration Trench Inputs*

| | Unit | Expected Value |
|---|---|---|
| **Name of feature** | | Infiltration Trench |
| **Area** | sq ft | 1,000 |
| **Depth of Coverage Materials** | Inches | 24 |
| **Percent Empty Space in Material** | % | 40 |
| **Rate of Gray Discharge from Outlet of Feature** | - | - |
| **Soil type** | | B |
| **Maximum Surface Infiltration Rate** | Inches per hour | 4.5 |
| **Minimum Surface Infiltration Rate** | Inches per hour | 0.25 |
| **Infiltration Rate Reduction Factor** | per hour | 1 |
| **Capital Expenditure** | $ | $1,450<br>(Low = $400, High = $4,200) |
| **Annual O&M** | $ | $120<br>(Low = $97, High = $151) |

**Notes:**

- CapEx is from EPA's SUSTAIN database and includes: backfilling, excavation, filter fabric, grading/finishing, grass, gravel, mulch, observation well, perennials, soil/planting media.
- O&M costs are from Watershed Management Group estimates based on $120/1,000 sq ft at a rate of $75/hr.

*Figure 6: Infiltration Trench*
*Source: PIMA County, 2015. "Low Impact Development and Green Infrastructure Guidance Manual".*

#### 2.2.2.4 Pervious Pavers

*Table 7: 1,000 sq ft Feature Type Pervious Pavers Inputs*

| | Unit | Expected Value |
|---|---|---|
| **Name of feature** | | Pervious pavers |
| **Area** | Sq ft | 1,000 |
| **Depth of Coverage Materials** | Inches | 3 |
| **Percent Empty Space in Material** | % | 20 |
| **Rate of Gray Discharge from Outlet of Feature** | - | - |
| **Soil type** | | B |
| **Maximum Surface Infiltration Rate** | Inches per hour | 4.5 |
| **Minimum Surface Infiltration Rate** | Inches per hour | 0.25 |
| **Infiltration Rate Reduction Factor** | per hour | 1 |
| **Capital Expenditure** | $ | $12,970<br>(Low = $7,540, High = $17,800) |
| **Annual O&M** | $ | $24<br>(Low = $12, High = $48) |

**Notes:**

- CapEx: Expected = using Taylor Mall 100 Plan Cost Model. Low and High from SUSTAIN.
- O&M costs calculated from Glendale Park and Ride at 99th Ave, which is porous concrete. O&M cost for power washing for FY 2017 was $2,580 across an area of 214,053 sq ft. Low = 1 wash per year, Expected = 2 times per year, High = 4 times per year.

*Figure 7: Pervious Pavers (Interlocking Porous Concrete Pavers)*
*Source: City of Phoenix, Office of Environmental Programs.*

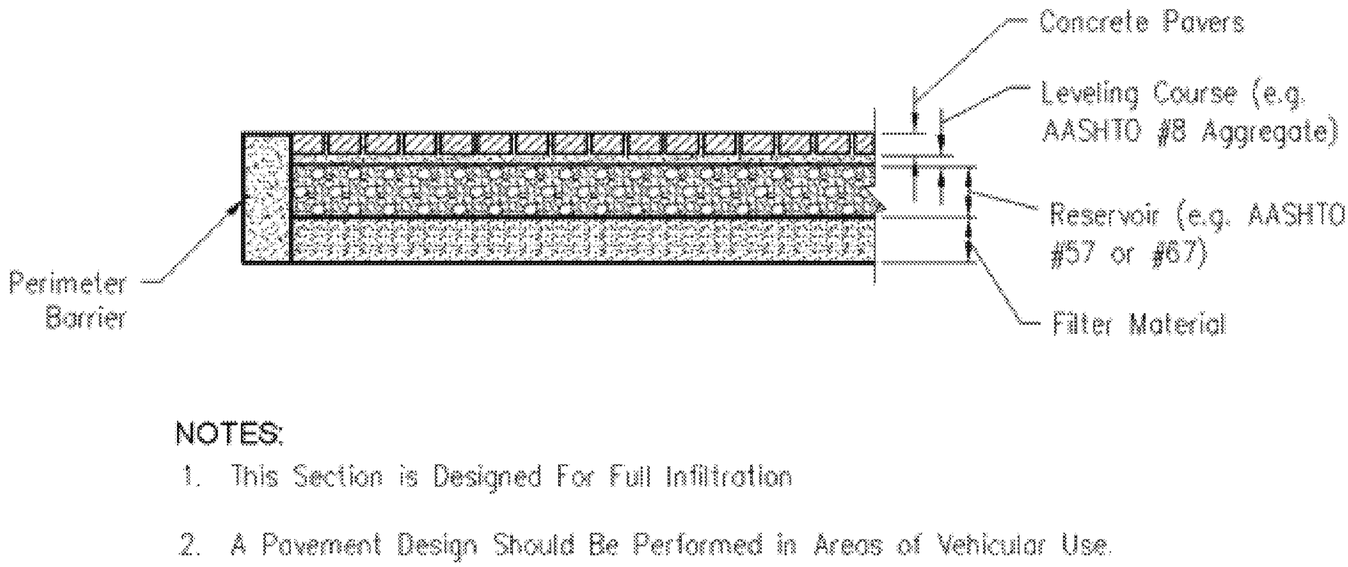


*Figure 8: Design Detail for Typical Pervious Pavers*
*Source: PIMA County, 2015. "Low Impact Development and Green Infrastructure Guidance Manual".*

#### 2.2.2.5 Porous Concrete

*Table 8: 1,000 sq ft Feature Type Porous Concrete Inputs*

| | Unit | Expected value |
|---|---|---|
| **Name of feature** | | Porous concrete |
| **Area** | Sq ft | 1,000 |
| **Depth of Coverage Materials** | Inches | 4 |
| **Percent Empty Space in Material** | % | 20 |
| **Rate of Gray Discharge from Outlet of Feature** | - | 0 |
| **Soil type** | | B |
| **Maximum Surface Infiltration Rate** | Inches per hour | 4.5 |
| **Minimum Surface Infiltration Rate** | Inches per hour | 0.25 |
| **Infiltration Rate Reduction Factor** | per hour | 1 |
| **Capital Expenditure** | $ | $7,000 (Low = $6,370, High = $10,670) |
| **Annual O&M** | $ | $24 (Low = $12, High = $48) |

**Notes:**

- CapEx: Expected = Site specific cost from the line items taken from Central Station Upgrades. Low and High values taken from SUSTAIN.
- O&M costs calculated from Glendale Park and Ride at 99th Ave, which is porous concrete. O&M cost for power washing for FY 2017 was $2,580 across an area of 214,053 sq ft. Low = 1 wash per year, Expected = 2 times per year, High = 4 times per year

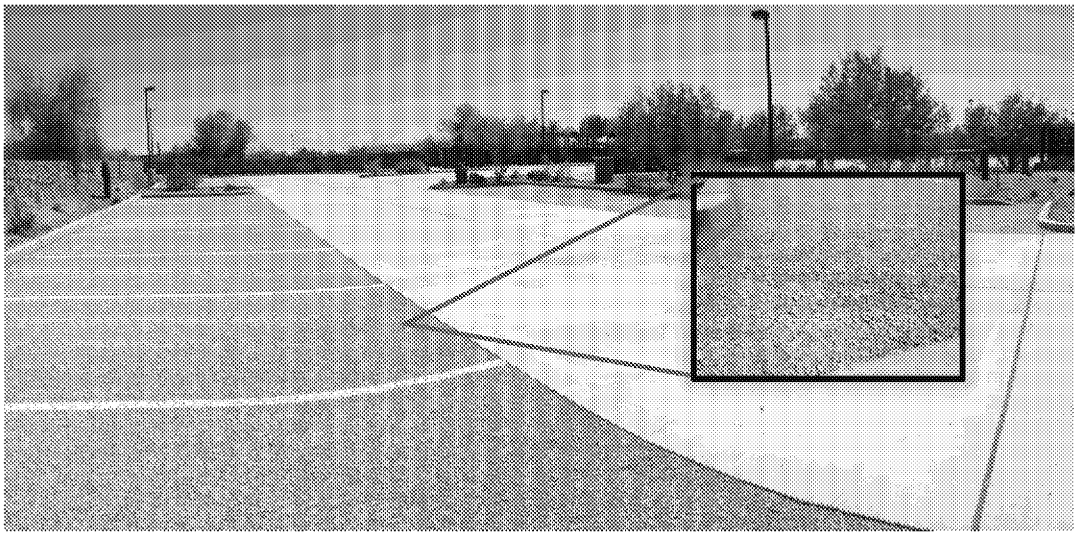

*Figure 9: Example Porous Concrete Installation*
*Source: City of Phoenix, Office of Environmental Programs*

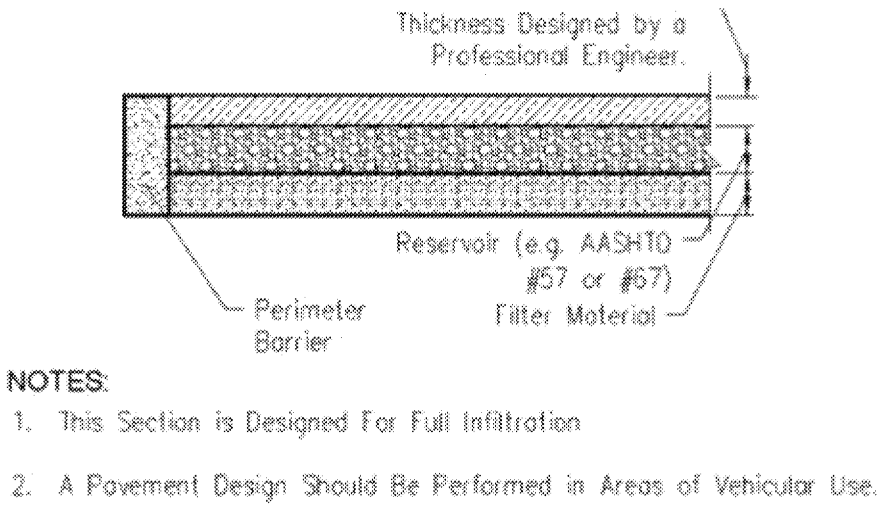


*Figure 10: Porous Concrete Detail*
*Source: PIMA County, 2015. "Low Impact Development and Green Infrastructure Guidance Manual".*
*Note: Taken from page 117. In the source above, the picture says "Pervious Concrete Pavers but is referring to porous concrete.*

### 2.2.2.6 Porous Asphalt

*Table 9: 1,000 sq ft Feature Type Asphalt Inputs*

| | Unit | Expected Value |
|---|---|---|
| **Name of feature** | | Porous asphalt |
| **Area** | Sq ft | 1,000 |
| **Depth of Coverage Materials** | Inches | 3 |
| **Percent Empty Space in Material** | % | 20 |
| **Rate of Gray Discharge from Outlet of Feature** | - | - |
| **Soil type** | | B |
| **Maximum Surface Infiltration Rate** | Inches per hour | 4.5 |
| **Minimum Surface Infiltration Rate** | Inches per hour | 0.25 |
| **Infiltration Rate Reduction Factor** | per hour | 1 |
| **Capital Expenditure** | $ | $6,330<br>(Low = $2,840, High = $9,470 |
| **Annual O&M** | $ | $24<br>(Low = $12, High = $48). |

**Notes:**

- Autocase default from SUSTAIN including: Excavation, Filter Fabric, Grading/finishing, Gravel, Observation Well, and Underdrain Pipe.
- O&M costs calculated from Glendale Park and Ride at 99th Ave, which is porous concrete. O&M cost for power washing for FY 2017 was $2,580 across an area of 214,053 sq ft. Low = 1 wash per year, Expected = 2 times per year, High = 4 times per year.

*Figure 11: Porous Asphalt*
*Source: Stantec*

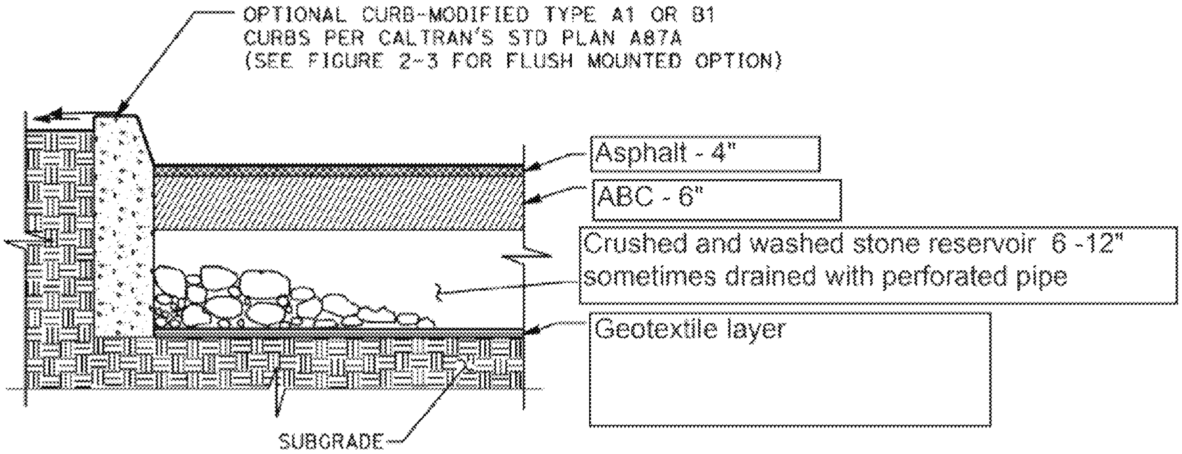


*Figure 12: Design Detail for Typical Asphalt*
*Source: Stantec*

# 3 Triple Bottom Line Net Present Value Results (GI/LID Feature Types)

This Section provides an overview of the results of the general feature type analysis that was presented in the previous section. Dollar amounts reflect costs and benefits estimated for the full 50-year life cycle used for each feature where the area of each feature is 1,000 square feet.

The tables and graphs that follow show the total cost of ownership of each feature, along with the social and environmental benefits that are generated over the 50-year time horizon. Negative numbers represent a cost or disbenefit (financial, social, or environmental), whereas positive numbers illustrate a saving or benefit; the larger the number, the greater the cost or benefit.

## 3.1 Summary of Results

### 3.1.1 Summary of Results Absolute

A summary of the Absolute financial, social, and environmental impacts for each feature type are given in Table 10. Absolute values are those that address each feature type individually without reference or comparison to the base case of concrete. Figure 13 represents these results visually.

From a purely financial perspective, Concrete (-$7,400), Bioretention basins (-$7,600) and Infiltration trenches (-$5,500) are the least expensive to build and operate over 50 years, whereas Pervious pavers are the most expensive (-$18,500). From a social perspective, Swales and Bioretention basins generate the most social impact at around $11,800 and $11,700, respectively. Concrete ($1,800), Infiltration trench ($1,200), and Porous asphalt ($1,000) generate the least social benefit. In terms of environmental benefits, Swale and Bioretention basin both generate the most environmental benefits at around $4,300 each over 50 years. The Concrete feature generates the worst impact at -$3,200. Looking at the overall TBL-NPV, we can see that only Swale and Bioretention basin are positive ($6,200 and $8,300). The largest negative TBL-NPVs are Concrete, Pervious pavers, and Porous asphalt at -$8,800 and -$14,200, and -$6,600 respectively.

We must note that these are Absolute results, and in order to make a comparison against a base case of Concrete, we need to identify the incremental differences between each LID feature and the base case of Concrete (i.e. a Relative analysis).

*Table 10: Summary of Absolute Triple Bottom Line Results ($/1,000 sq ft)*

| | Concrete (base case) | Swale | Bioret'n Basin | Infiltration Trench | Pervious Pavers | Porous Concrete | Porous Asphalt |
|---|---|---|---|---|---|---|---|
| Financial | -$7,426 | -$9,856 | -$7,627 | -$5,465 | -$18,494 | -$10,638 | -$9,563 |
| Social | $1,809 | $11,775 | $11,655 | $1,165 | $2,364 | $2,623 | $1,019 |
| Environmental | -$3,176 | $4,313 | $4,300 | $1,661 | $1,912 | $1,912 | $1,912 |
| **Triple Bottom Line NPV** | **-$8,793** | **$6,233** | **$8,328** | **-$2,638** | **-$14,218** | **-$6,102** | **-$6,632** |

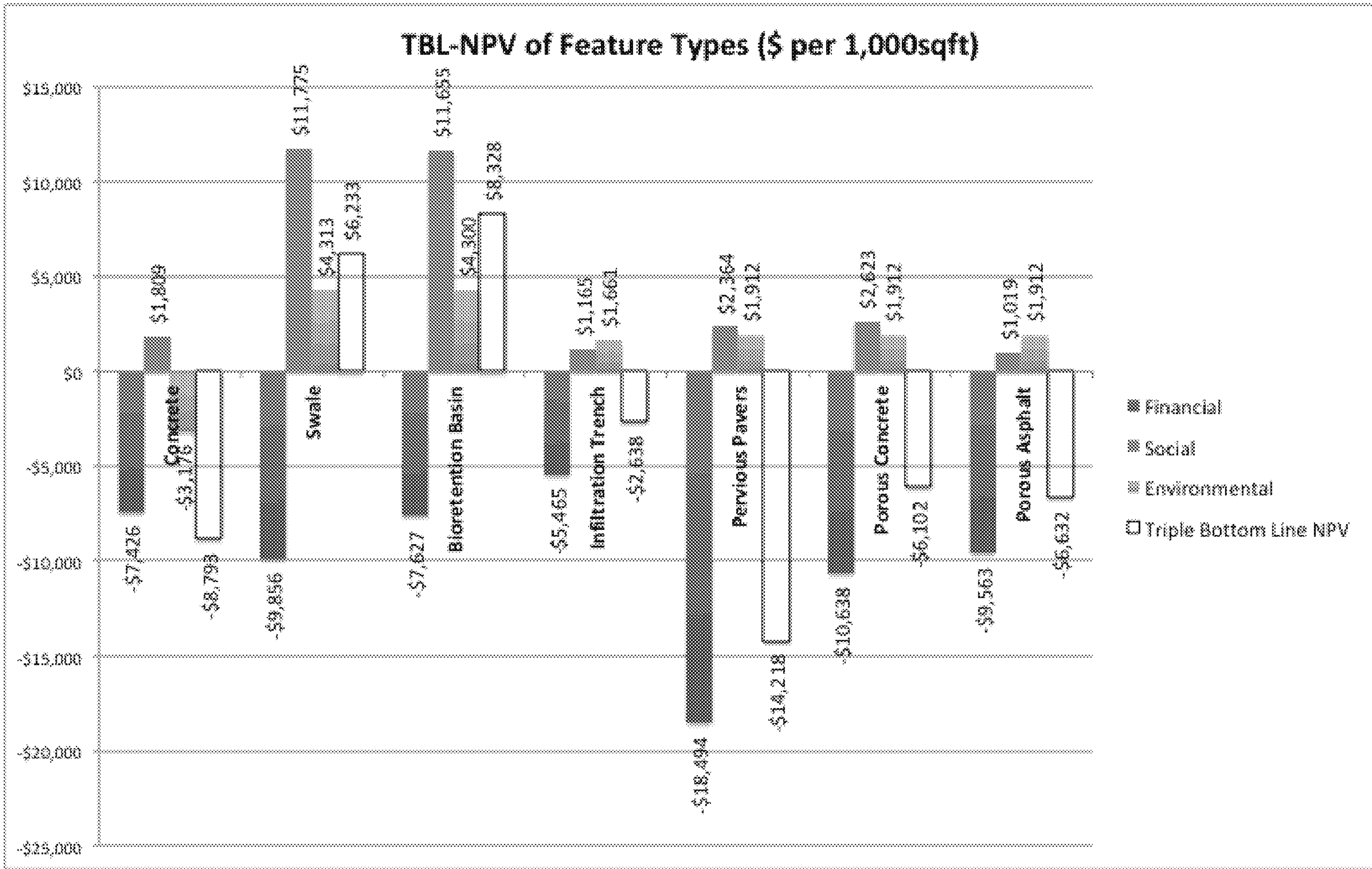


*Figure 13: Absolute TBL-NPV Results of Feature Types ($ per 1,000 sq ft)*

### 3.1.2 Summary of Results: Relative

A summary of the Relative – or incremental (i.e. versus Concrete base case) financial, social, and environmental impacts for each feature type are given in Table 11. Figure 14 offers a visual representation of these.

From a purely financial perspective, only Infiltration trench is cheaper than concrete over 50 years at around $2,000 in savings. All other features are more expensive, with Pervious pavers are about $11,100 more expensive per 1,000 sq ft. In terms of social impacts, Swale and Bioretention basin stand out as winners – generating almost an additional $10,000 each. Only Infiltration trench and Porous asphalt generate negative social impacts at -$600 and -$800. Environmentally, all features perform better than Concrete[1], with Swale and Bioretention basin each generating around $7,500 additional benefit, while the lowest – Infiltration trench still generates almost $5,000 more than Concrete. Finally, in terms of TBL-NPV, all but Pervious pavers (-$1,000) generate positive TBL-NPV, with Swale ($15,000) and Bioretention basin ($17,100) the clear leaders.

*Table 11: Summary of Relative Triple Bottom Line Results Compared to Concrete ($/1,000 sq ft)*

| | Swale | Bioretent'n Basin | Infiltration Trench | Pervious Pavers | Porous Concrete | Porous Asphalt |
|---|---|---|---|---|---|---|
| Financial | -$2,429 | -$200 | $1,962 | -$11,067 | -$3,211 | -$2,136 |
| Social | $9,966 | $9,846 | -$644 | $555 | $814 | -$790 |
| Environmental | $7,489 | $7,476 | $4,837 | $5,088 | $5,088 | $5,088 |
| **Triple Bottom Line NPV** | **$15,026** | **$17,122** | **$6,155** | **-$5,424** | **$2,691** | **$2,162** |

[1] The environmental benefits are consistently large across the features; this is primarily due to two factors: 1) avoided carbon from concrete production being the same across the board; and 2) the similar infiltration rates of the features, which feeds into the flood risk and water quality benefits. Both these impacts generate large value (as will be seen in the detailed tables below).

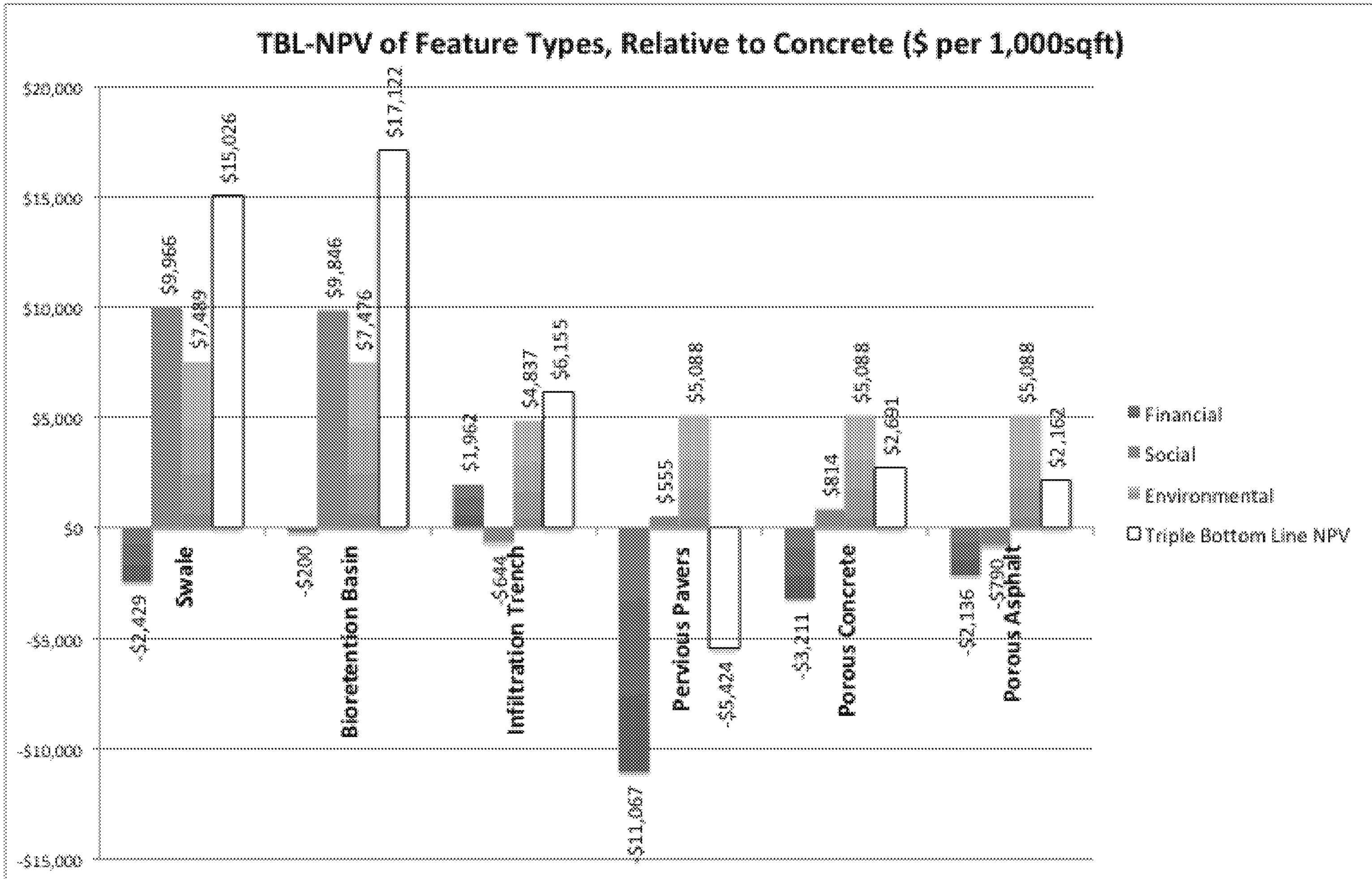


*Figure 14: TBL-NPV Results of Feature Types Relative to Concrete ($ per 1,000 sq ft)*

## 3.2 Detailed results

Table 12 breaks down the Absolute results for the feature types by each impact type – or parameter. Table 13 provides the Relative (i.e. vs. concrete) value for each feature by impact type. For a more detailed breakdown of the results, which include the 95% confidence intervals for each cost and benefit, please see the following sections. Positive numbers represent a benefit or value generation, while negative numbers are additional costs or dis-benefit generated.

### 3.2.1 Detailed Results: Absolute

From Table 12, we can dive deeper to identify the driving forces of value for each feature on an absolute basis. For example, from a financial perspective we can see that O&M for Swale (-$3,200), Bioretention basin (-$3,200), and Infiltration Trench (-$3,100) are a considerable cost factor compared to their CapEx, whereas Replacement cost are a dominant force for Pervious pavers (-$6,000), Porous concrete (-$2,800), and Porous asphalt (-$3,100). From a social perspective, Swale and Bioretention basin generate significant Heat island effect benefits at around $10,000 each.

Environmentally, the biggest water quality benefits are created by Swale ($2,700) and Bioretention basin ($2,600), however Pervious pavers, Porous concrete, and Porous asphalt still generate almost $2,000 each. The use of Concrete generates carbon emissions valued at around -$3,200. Swale and Bioretention basin also generate benefits from reduced $CO_2$ and air pollution caused by vegetation as well as lower energy use.

*Table 12: Absolute TBL-CBA Values for Each Feature by Impact Type ($/1,000sq ft)*

| Impact Type | Cost/Benefit | Concrete (Base Case) | Swale | Bioret'n Basin | Infiltrat'n Trench | Pervious Pavers | Porous Concrete | Porous Asphalt |
|---|---|---|---|---|---|---|---|---|
| Financial | Capital Expenditures | -$5,796 | -$5,820 | -$3,022 | -$1,715 | -$12,976 | -$7,596 | -$6,321 |
| Financial | Operations and Maintenance | $0 | -$3,165 | -$3,170 | -$3,115 | -$676 | -$675 | -$675 |
| Financial | CapEx on Additional Detention | -$24 | $0 | $0 | $0 | $0 | $0 | 0 |
| Financial | O&M on Additional Detention | -$6 | $0 | $0 | $0 | $0 | $0 | 0 |
| Financial | CapEx on Additional Piping | -$505 | $0 | $0 | $0 | $0 | $0 | 0 |
| Financial | O&M on Additional Piping | -$76 | $0 | $0 | $0 | $0 | $0 | 0 |
| Financial | Replacement Costs | -$1,452 | -$1,371 | -$1,662 | -$672 | -$5,906 | -$2,788 | -$3,124 |
| Financial | Residual Value of Assets | $431 | $501 | $227 | $38 | $1,064 | $422 | $558 |
| Social | Heat Island Effect (Mortality) | $1,807 | $10,041 | $10,369 | $0 | $1,753 | $1,997 | $409 |
| Social | Heat Island Effect (Morbidity) | $2 | $6 | $6 | $1 | $2 | $2 | $0 |
| Social | Flood Risk | $0 | $1,421 | $1,151 | $1,036 | $481 | $495 | $481 |
| Social | Property Value | $0 | $308 | $129 | $128 | $129 | $129 | $129 |
| Environmental | Water quality | $0 | $2,682 | $2,629 | $1,661 | $1,912 | $1,912 | $1,912 |
| Environmental | Carbon Emissions from Concrete | -$3,176 | $0 | $0 | $0 | $0 | $0 | 0 |
| Environmental | Air Pollution Reduced by Vegetation | $0 | $1,033 | $1,080 | $0 | $0 | $0 | 0 |
| Environmental | Carbon Reduction by Vegetation | $0 | $76 | $70 | $0 | $0 | $0 | 0 |
| Environmental | Air Pollution Reduced by Energy Use | $0 | $290 | $290 | $0 | $0 | $0 | 0 |
| Environmental | Carbon Reduction by Energy Use | $0 | $231 | $231 | $0 | $0 | $0 | 0 |
| **Total:** | **TBL-NPV** | **-$8,793** | **$6,233** | **$8,328** | **-$2,638** | **-$14,218** | **-$6,102** | **-$6,632** |

### 3.2.2 Detailed Results: Relative

Table 13 enables us to see where benefits – or dis-benefits – are being created relative to a Concrete base case. Looking at the financial impacts, some interesting factors emerge. In terms of CapEx, Swale costs roughly the same as Concrete, Bioretention basin and Infiltration trench cost less by around $2,800 and $4,100, respectively, while Pervious pavers cost about $7,200 more per 1,000 sq ft. For O&M, all features are more expensive than Concrete; Swale, Bioretention basin, and Infiltration trench cost around $3,000 more over 50 years, while Pervious pavers, Porous concrete, and Porous asphalt only cost around $700 more due to the lack of vegetation maintenance associated with them. We also see that there are small cost savings ($600) associated with additional piping and detention for all features versus Concrete.

Regarding social factors, we can see that the vegetated features i.e. Swale and Bioretention generate significant heat island effect benefits compared to Concrete. By factoring in future temperature predictions using NOAA's Climate Explorer, we can see how each feature will impact heat risk mortality under higher temperatures than those currently felt. Infiltration trench and Porous asphalt create disbenefits compared to Concrete from heat risk mortality due to their darker surface. For flood risk, given that all features have a higher infiltration rate compared to Concrete, each one generates a benefit, with the vegetated features creating the most ($1,000 to $1,500) compared to Pervious pavers, Porous concrete, and Porous asphalt ($500).

There are some significant environmental benefits created by GI/LID features when compared to Concrete. Firstly, water quality improvements due to reduced runoff range from around $2,700 for Swale to almost $2,000 for Porous concrete. Each feature achieves a benefit of around $3,200 in avoided carbon emissions from Concrete. Lastly, the Swale and Bioretention basin each generate around $1,600 in reduced carbon emissions and air pollution from vegetation and avoided energy use due to shading.

*Table 13: Relative TBL-NPV Results for Each Feature by Impact Type Compared to Concrete ($/1,000 sq ft)*

| Impact Type | Cost/Benefit | Swale | Bioret'n Basin | Infiltrat'n Trench | Pervious Pavers | Porous Concrete | Porous Asphalt |
|---|---|---|---|---|---|---|---|
| Financial | Capital Expenditures | -$24 | $2,774 | $4,081 | -$7,180 | -$1,800 | -$526 |
| Financial | Operations and Maintenance | -$3,165 | -$3,170 | -$3,115 | -$676 | -$675 | -$675 |
| Financial | CapEx on Additional Detention | $24 | $24 | $24 | $24 | $24 | $24 |
| Financial | O&M on Additional Detention | $6 | $6 | $6 | $6 | $6 | $6 |
| Financial | CapEx on Additional Piping | $505 | $505 | $505 | $505 | $505 | $505 |
| Financial | O&M on Additional Piping | $76 | $76 | $76 | $76 | $76 | $76 |
| Financial | Replacement Costs | $81 | -$210 | $780 | -$4,454 | -$1,336 | -$1,672 |
| Financial | Residual Value of Assets | $69 | -$204 | -$394 | $633 | -$10 | $126 |
| Social | Heat Island Effect (Mortality) | $8,233 | $8,562 | -$1,807 | -$55 | $190 | -$1,398 |
| Social | Heat Island Effect (Morbidity) | $4 | $4 | -$1 | $0 | $1 | -$1 |
| Social | Flood Risk | $1,421 | $1,151 | $1,036 | $481 | $495 | $481 |
| Social | Property Value | $308 | $129 | $128 | $129 | $129 | $129 |
| Environmental | Water quality | $2,682 | $2,629 | $1,661 | $1,912 | $1,912 | $1,912 |
| Environmental | Carbon Emissions from Concrete | $3,176 | $3,176 | $3,176 | $3,176 | $3,176 | $3,176 |
| Environmental | Air Pollution Reduced by Vegetation | $1,033 | $1,080 | $0 | $0 | $0 | $0 |
| Environmental | Carbon Reduction by Vegetation | $76 | $70 | $0 | $0 | $0 | $0 |
| Environmental | Air Pollution Reduced by Energy Use | $290 | $290 | $0 | $0 | $0 | $0 |
| Environmental | Carbon Reduction by Energy Use | $231 | $231 | $0 | $0 | $0 | $0 |
| **Total:** | **TBL-NPV** | **$15,026** | **$17,122** | **$6,155** | **-$5,424** | **$2,691** | **$2,162** |

## 3.3 Swales

Swales generate an estimated $15,026 (95% confidence interval of -$2,151 to $33,600) in triple bottom line net present value over a 50-year time horizon relative to Concrete, with -$2,400 created through financial impacts, $10,000 through social benefits, and $7,500 through environmental benefits.

Figure 15 shows a waterfall chart of the breakdown of these values. On the chart, blue represents value being created, whereas red represents a cost, relative to concrete. We can see that Swales have almost no incremental capital expenditure (CapEx) but do have higher operations & maintenance (O&M) costs compared to Concrete. We can see that varying amounts of value are created across the social and environmental spectrum of impacts, with the most significant being heat island benefit ($8,200), flood risk ($1,400), water quality ($2,700), and avoided carbon emissions from concrete use ($3,200).

The 95% confidence intervals shown in Table 14 allow us to see the uncertainty in some of these figures. For example, CapEx and Replacement costs could be higher or lower than Concrete. There is a large spread in heat island benefits ($4,603 to $12,005), as well as water quality ($453 to $5,561), and when all impacts have been assessed it creates a large spread in overall TBL-NPV (-$2,151 to $33,600) but reveals a small chance of generating a negative TBL-NPV as compared to Concrete.

| Financial | Social | Environmental |
|---|---|---|
| -$2,429 | $9,966 | $7,489 |
| **Triple Bottom Line NPV** | | **$15,026** |

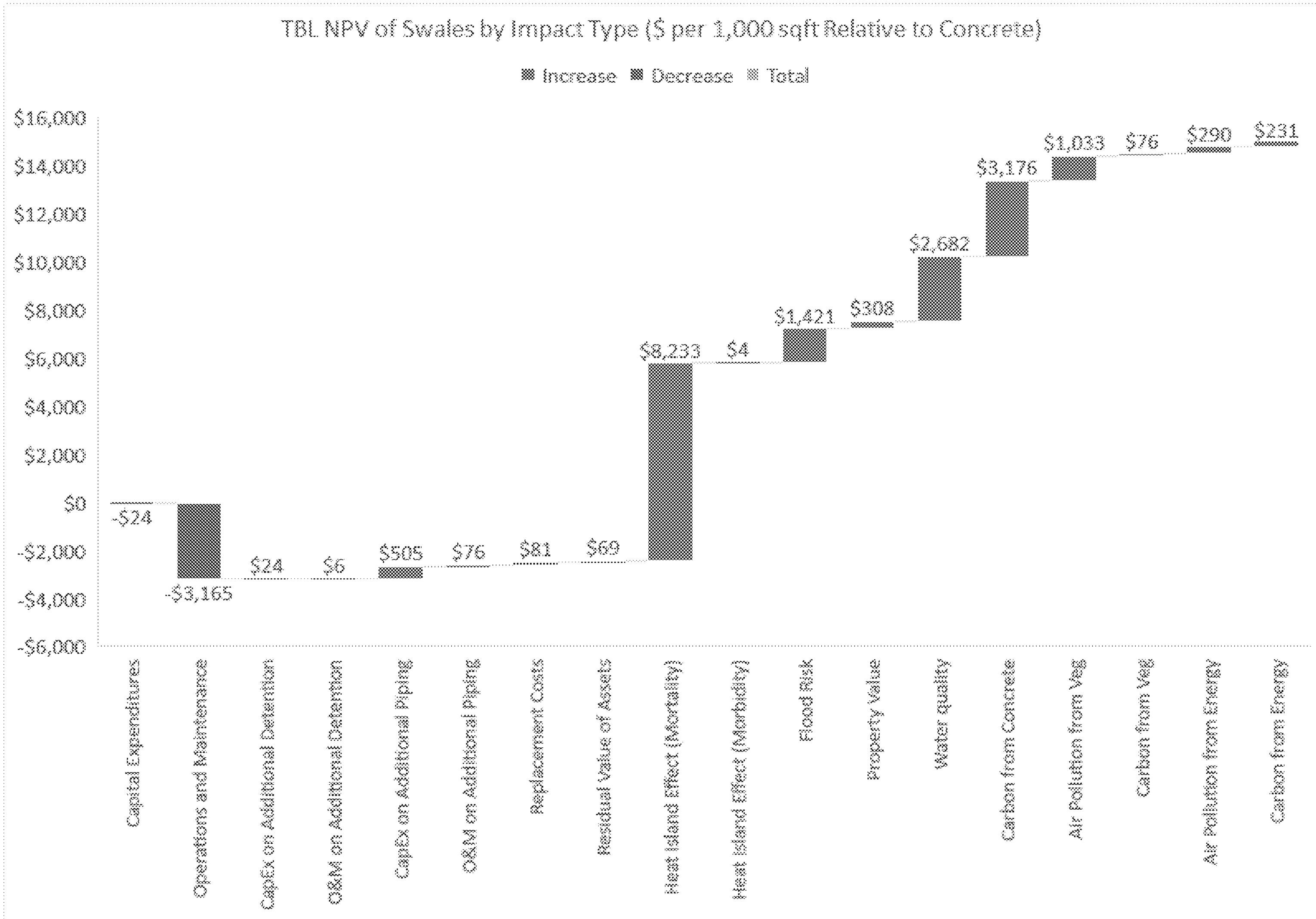


*Figure 15: Breakdown of TBL NPV for Swales*

*Table 14: Swale Relative Results Compared to Concrete with 95% CI ($/1,000 sq ft)*

| Impact Type | Cost/Benefit | Mean Value | 95% Confidence Interval | | |
|---|---|---|---|---|---|
| Financial | Capital Expenditures | **-$24** | -$4,802 | to | $4,188 |
| Financial | Operations and Maintenance | **-$3,165** | -$3,650 | to | -$2,675 |
| Financial | CapEx on Additional Detention | **$24** | $9 | to | $39 |
| Financial | O&M on Additional Detention | **$6** | $0 | to | $11 |
| Financial | CapEx on Additional Piping | **$505** | $403 | to | $642 |
| Financial | O&M on Additional Piping | **$76** | $45 | to | $110 |
| Financial | Replacement Costs | **$81** | -$2,290 | to | $2,589 |
| Financial | Residual Value of Assets | **$69** | -$820 | to | $1,058 |
| Social | Heat Island Effect (Mortality) | **$8,233** | $4,603 | to | $12,005 |
| Social | Heat Island Effect (Morbidity) | **$4** | -$2 | to | $12 |
| Social | Flood Risk | **$1,421** | $1,408 | to | $1,433 |
| Social | Property Value | **$308** | $205 | to | $429 |
| Environmental | Water quality | **$2,682** | $453 | to | $5,561 |
| Environmental | Carbon Emissions from Concrete | **$3,176** | $1,294 | to | $5,771 |
| Environmental | Air Pollution Reduced by Vegetation | **$1,033** | $696 | to | $1,380 |
| Environmental | Carbon Reduction by Vegetation | **$76** | $31 | to | $140 |
| Environmental | Air Pollution Reduced by Energy Use | **$290** | $173 | to | $460 |
| Environmental | Carbon Reduction by Energy Use | **$231** | $94 | to | $451 |

| | | | | | |
|---|---|---|---|---|---|
| **Total** | **Triple Bottom Line NPV** | **$15,026** | -$2,151 | to | $33,604 |

## 3.4 Bioretention Basin

Bioretention basin generates an estimated $17,122 (95% confidence interval of $4,300 to $32,300) in triple bottom line net present value over a 50-year time horizon relative to Concrete, with -$200 created through financial impacts, $9,800 through social benefits, and $7,500 through environmental benefits.

Figure 16 shows a waterfall chart of the breakdown of these values. On the chart, blue represents value being created, whereas red represents a cost, relative to concrete. We can see that Bioretention basins have a lower CapEx than Concrete but is outweighed by higher O&M. Varying amounts of value are created across the social and environmental spectrum of impacts, with the most significant being heat island benefit ($8,600), flood risk ($1,200), water quality ($2,600), and avoided carbon emissions from concrete use ($3,200).

The 95% confidence intervals shown in Table 15 allow us to see the uncertainty in some of these figures. There is a large spread in heat island benefits ($4,831 to $12,440), as well as water quality ($444 to $5,451), and when all impacts have been assessed it creates a large spread in overall TBL-NPV of $4,307 to $32,254; nevertheless, even at the low estimate we still generate a positive TBL-NPV as compared to Concrete.

| Financial | Social | Environmental |
|---|---|---|
| -$200 | $9,846 | $7,476 |

| | |
|---|---|
| **Triple Bottom Line NPV** | **$17,122** |

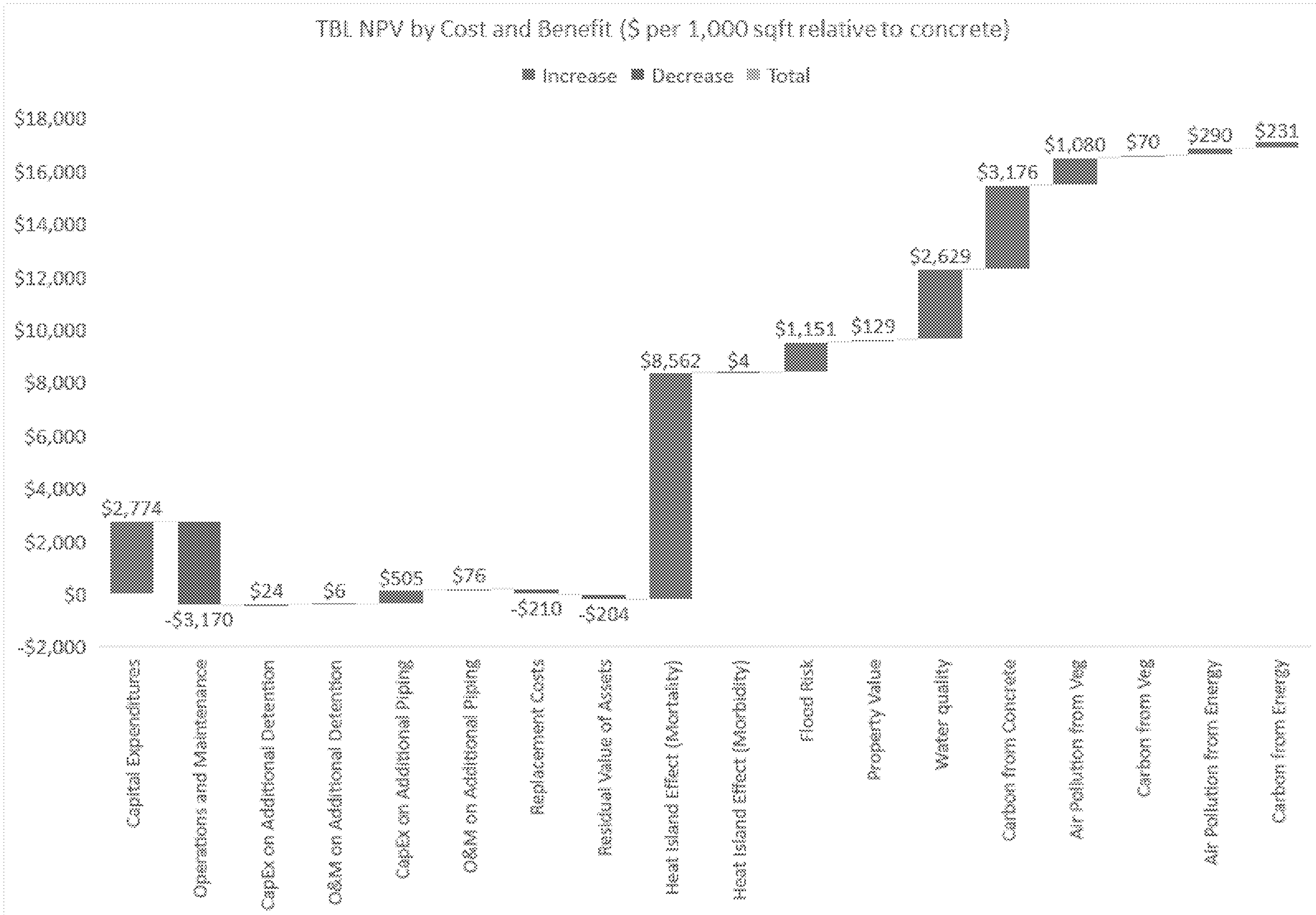


*Figure 16: Breakdown of TBL NPV for Bioretention Basins*

*Table 15: Bioretention Basin Relative Results Compared to Concrete with 95% CI ($/1,000 sq ft)*

| Impact Type | Cost/Benefit | Mean Value | 95% Confidence Interval | | |
|---|---|---|---|---|---|
| Financial | Capital Expenditures | **$2,774** | $1,133 | to | $4,400 |
| Financial | Operations and Maintenance | **-$3,170** | -$3,662 | to | -$2,680 |
| Financial | CapEx on Additional Detention | **$24** | $9 | to | $39 |
| Financial | O&M on Additional Detention | **$6** | $0 | to | $11 |
| Financial | CapEx on Additional Piping | **$505** | $403 | to | $642 |
| Financial | O&M on Additional Piping | **$76** | $45 | to | $110 |
| Financial | Replacement Costs | **-$210** | -$1,713 | to | $1,978 |
| Financial | Residual Value of Assets | **-$204** | -$723 | to | $266 |
| Social | Heat Island Effect (Mortality) | **$8,562** | $4,831 | to | $12,440 |
| Social | Heat Island Effect (Morbidity) | **$4** | -$2 | to | $12 |
| Social | Flood Risk | **$1,151** | $1,138 | to | $1,163 |
| Social | Property Value | **$129** | $81 | to | $183 |
| Environmental | Water quality | **$2,629** | $444 | to | $5,451 |
| Environmental | Carbon Emissions from Concrete | **$3,176** | $1,294 | to | $5,771 |
| Environmental | Air Pollution Reduced by Vegetation | **$1,080** | $732 | to | $1,428 |
| Environmental | Carbon Reduction by Vegetation | **$70** | $29 | to | $129 |
| Environmental | Air Pollution Reduced by Energy Use | **$290** | $173 | to | $460 |
| Environmental | Carbon Reduction by Energy Use | **$231** | $94 | to | $451 |
| **Total** | **Triple Bottom Line NPV** | **$17,122** | $4,307 | to | $32,254 |

## 3.5 Infiltration Trench

Infiltration trench generates an estimated $6,200 (95% confidence interval of -$2,601 to $15,815) in triple bottom line net present value over a 50-year time horizon relative to Concrete, with $2,000 created through financial savings, -$600 through social impacts, and $4,800 through environmental benefits.

Figure 17 shows a waterfall chart of the breakdown of these values. On the chart, blue represents value being created, whereas red represents a cost, relative to concrete. We can see that Infiltration trenches have a lower CapEx than Concrete; this saving outweighs the higher O&M. Varying amounts of value (as well as dis-benefits) are created across the social and environmental spectrum of impacts, with the most significant being heat island benefit (-$1,800), flood risk ($1,000), water quality ($1,700), and avoided carbon emissions from concrete use ($3,200).

The 95% confidence intervals shown in Table 16 allow us to see the uncertainty in some of these figures. There is a large spread in CapEx ($1,471 to $6,056), as well as water quality ($280 to $3,444), and when all impacts have been assessed it creates a large spread in overall TBL-NPV of -$2,601 to $15,815, showing that there is a possibility – albeit small – of negative TBL-NPV compared to Concrete.

| Financial | Social | Environmental |
|---|---|---|
| $1,962 | -$644 | $4,837 |

| | |
|---|---|
| **Triple Bottom Line NPV** | **$6,155** |

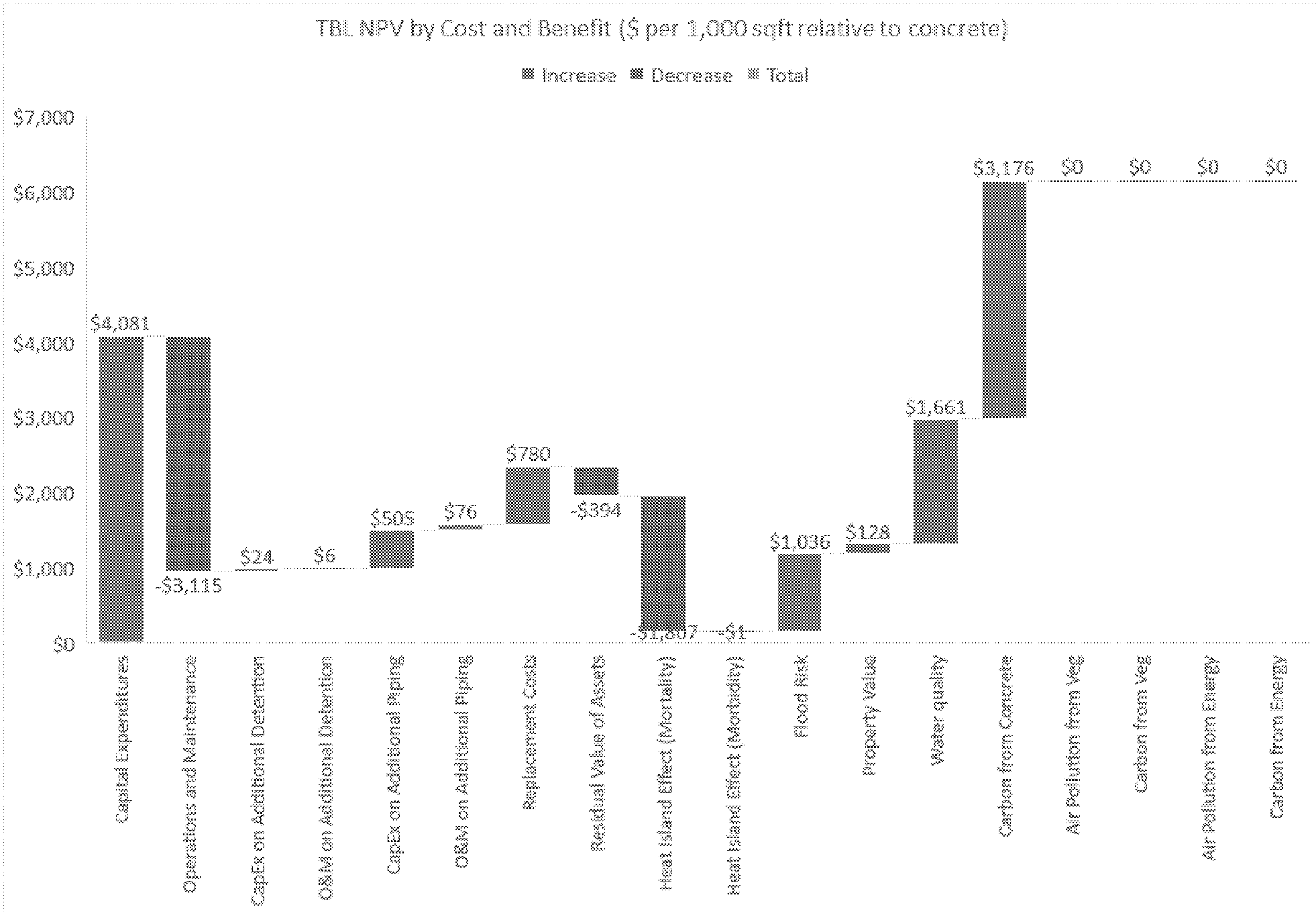


*Figure 17: Breakdown of TBL NPV for Infiltration Trenches*

*Table 16: Infiltration Trench Relative Results Compared to Concrete with 95% CI ($/1,000 sq ft*

| Impact Type | Cost/Benefit | Mean Value | 95% Confidence Interval | | |
|---|---|---|---|---|---|
| Financial | Capital Expenditures | **$4,081** | $1,471 | to | $6,056 |
| Financial | Operations and Maintenance | **-$3,115** | -$3,115 | to | -$3,115 |
| Financial | CapEx on Additional Detention | **$24** | $9 | to | $39 |
| Financial | O&M on Additional Detention | **$6** | $0 | to | $11 |
| Financial | CapEx on Additional Piping | **$505** | $403 | to | $642 |
| Financial | O&M on Additional Piping | **$76** | $45 | to | $110 |
| Financial | Replacement Costs | **$780** | -$846 | to | $2,859 |
| Financial | Residual Value of Assets | **-$394** | -$868 | to | $45 |
| Social | Heat Island Effect (Mortality) | **-$1,807** | -$2,387 | to | -$1,258 |
| Social | Heat Island Effect (Morbidity) | **-$1** | -$3 | to | $0 |
| Social | Flood Risk | **$1,036** | $1,036 | to | $1,036 |
| Social | Property Value | **$128** | $81 | to | $175 |
| Environmental | Water quality | **$1,661** | $280 | to | $3,444 |
| Environmental | Carbon Emissions from Concrete | **$3,176** | $1,294 | to | $5,771 |
| Environmental | Air Pollution Reduced by Vegetation | **$0** | $0 | to | $0 |
| Environmental | Carbon Reduction by Vegetation | **$0** | $0 | to | $0 |
| Environmental | Air Pollution Reduced by Energy Use | **$0** | $0 | to | $0 |
| Environmental | Carbon Reduction by Energy Use | **$0** | $0 | to | $0 |

| | | | | | |
|---|---|---|---|---|---|
| **Total** | **Triple Bottom Line NPV** | **$6,155** | -$2,601 | to | $15,815 |

## 3.6 Pervious Pavers

Pervious pavers generate an estimated -$5,400 (95% confidence interval of -$21,411 to $12,068) in triple bottom line net present value over a 50-year time horizon relative to Concrete, with -$11,100 created through financial impacts, $600 through social impacts, and $5,100 through environmental benefits.

Figure 18 shows a waterfall chart of the breakdown of these values. On the chart, blue represents value being created, whereas red represents a cost, relative to concrete. We can see that Pervious pavers have a much higher CapEx and replacement cost than Concrete. Varying amounts of value are created across the social and environmental spectrum of impacts, with the most significant being flood risk ($500), water quality ($1,900), and avoided carbon emissions from concrete use ($3,200).

The 95% confidence intervals shown in Table 17 allow us to see the uncertainty in some of these figures. There is a large spread in CapEx (-$11,670 to -$2,323), as well as water quality ($323 to $3,963), and when all impacts have been assessed it creates a large spread in overall TBL-NPV of -$21,411 to $12,068, indicating that there is a fair possibility of either a positive or negative TBL-NPV compared to Concrete.

| Financial | Social | Environmental |
|---|---|---|
| -$11,067 | $555 | $5,088 |
| **Triple Bottom Line NPV** | | **-$5,424** |